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DRAWINGS ATTACHED

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Computer controlled wheel braking system.

COMPLETE SPECIFICATION

We, SOCIETE D'EXPLOITATION DES MATERIELS HISPANOSUIZA, a French Body Corporate of rue du Capitaine Guynemer, Bois-Colombes (Seine) France, do hereby declare the invention, for which we pray that a patent may be granted to us and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to vehicle braking systems and particularly to automatically controlled vehicle braking systems.

The present invention is directed towards servo-controlled braking systems either for vehicles which maintain a permanent contact with the ground (land vehicles), or for those which are only temporily in contact therewith (aircraft), such systems including, in a general manner, braking devices comprising at least one servo-control of any type appropriately arranged so as to be able to cause the application of a regulatable braking force to at least one wheel of the vehicle. The present description is more particularly directed towards devices of this type adapted for effecting the braking of aircraft. However, this is only for purposes of description and because such application appears to have the greatest interest at this time, and it should be appreciated that the present invention could be used equally well to control the braking of any other type of vehicle.

It is an object of this invention to reduce to a minimum the wear experienced by braking surfaces.

It is another object of this invention to increase the safety of aircraft landings, and remove the possibility of human error during the application of aircraft wheel brakes.

According to the present invention there is provided a braking system for vehicles adapted to run on the ground, comprising at least one servo-control arranged so as to be capable of producing on at least one wheel of radius R and of inertia moment I belonging to the vehicle to be braked an adjustable braking torque, the said servo-control being subjected to an electronic system into which is introduced information relating to the movements of the said vehicle, more particularly information relating to the speed V of the vehicle itself, the braking torque C exerted on the braked wheel and the instantaneous angular speed n of the said wheel, characterised in that the electronic system comprises a computer capable, at each instant and whatever the state of the ground, of producing a binary signal $\pm$ Ut of variable duration, the sign of this binary signal $\pm$ Ut being the sign of the derivative of the drag force $F=\frac{1}{R}(C-I\frac{dn}{dt})$ relatively to the slippage $g=1-\frac{nR}{V}$, whereas the duration of this binary signal $\pm$ Ut is equal to the time during which the said derivative $\frac{dF}{dg}$ retains the same sign, the sign of this derivative $\frac{dF}{dg}$ being determined directly or indirectly, of using the sign and the duration of this binary signal $\pm$ Ut to produce another signal g_o known as the "assigned slippage" signal representing a slippage better adapted to the conditions existing at the instant in question, this assigned slippage g_o corresponding to an angular speed n_o of the braked wheel known as the "assigned angular speed", and a regulator receiving, amongst other information, an information relating to the said desired angular speed n_o and an information relating to the instantaneous angular speed n of the braked

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wheel, the said regulator acting on the said servo-control in such a manner that the value of the instantaneous angular speed n is maintained at the value of the desired angular speed n_c calculated by the computer.

The invention is illustrated by way of example in the accompanying drawings, in which:

Fig. 1 is a block diagram of a complete automatic braking system according to the present invention;

Figs. 2 and 3 are graphs showing several relations involved in the operation of the systems of the present invention;

Figs. 4, 5 and 6 are schematic block diagrams of three embodiments of the control systems used in the system of Fig. 1;

Fig. 7 is a schematic diagram of the hydraulic system of the Fig. 1 device;

Fig. 8 is a diagrammatic view illustrating a different embodiment of a portion of a braking system;

Fig. 9 is an explanatory diagram; and

Fig. 10 is a diagrammatical view of a modification of the braking system.

One form which the present invention may take is shown in Fig. 1 as being housed within an aircraft equipped with a main landing gear 2 on which is mounted at least one wheel 3 furnished with brakes 3*a* which will be operated by a servo-control which is preferably, but not necessarily, of the hydraulic type.

Before proceeding with a discussion of the structure shown by the drawings certain considerations should be mentioned.

It is known that the efficacity of a wheel brake, particularly in terms of the braking torque C which can be developed, is often superior to that required under certain minimal load conditions (when the aircraft is empty for example) or certain ground surface conditions (when the runway is wet, for example), with the result that it is necessary to be able, at each instant, to adapt torque C to the then existing conditions.

However, the manual brake control systems currently available are incapable of obtaining an optimum braking control. Most of the automatic systems previously proposed have the same shortcoming, these systems being principally concerned with preventing the wheels from being locked, to avoid skidding, but not being capable of obtaining an optimum braking action.

In this condition it may be noted that a braking regulator should in order to achieve its full effectiveness, be able to adapt, at each instant and in an automatic manner, the braking torque to be exerted C to the maximum possible drag force F, this force being equal to the product of the coefficient of friction k between the tire and the ground and of the vertical load exerted on the wheel to which said tire is attached.

The natures of these two parameters will now be examined in detail.

In so far as concerns, first of all, the friction between the wheel and the ground, it is known that the coefficient of friction k depends on the relative speed between the two, this relative speed being dependent on two factors: the true ground speed V of the aircraft and the slippage g of the wheel, this slippage being defined at each instant by the relation

$$g = \frac{V - nR}{V},$$

where n is the speed of revolution of the wheel in radians/sec. and R is the wheel radius in units consistent with those used for V (preferably meters for R and meters/sec for V, respectively).

The variation of the coefficient of friction k as a function of g shows, as may be seen from Fig. 2, that k passes through a maximum k_1 at a slippage value g_1 generally ranging between 5% and 20% for a typical given value of V.

If the variations of this maximum coefficient of friction k_1 are plotted as a function of the aircraft speed V, it appears, as shown in Fig. 3, that k_1 decreases rapidly as speed V increases until k_1 reaches a relatively low value, after which it remains relatively constant for further increases in speed.

It should be appreciated that these two curves correspond only to the case of a surface whose characteristics remain constant over the entire path of travel of the aircraft. Such a condition is evidently not always fulfilled, the nature of the surface of a runway often varying due to many factors such as variations in the quality of surfacing of the runway from one point to another or the presence of areas of water, snow, ice or oil on the runway. It thus results that in reality there exists a whole family of curves similar to those of Figs. 2 and 3.

In so far as concerns the vertical load P exerted on the wheel in question, its average value is known for a given type of aircraft, but it nevertheless remains that the variations of P around its average value may be relatively large and that the causes of these variations, which can be foreseen in some cases (variations in the lift of the aircraft as a function or speed), cannot be foreseen in many other cases (e.g. due to unevenness in the runway surface) to such an extent that it is extremely difficult to know the actual value of P at each moment.

If, taking the above-discussed factors into consideration, one considers a short

period of time during which there is applied to the wheel a braking torque C superior to that called for by the value F of the drag force exerted on the wheel by the ground (the values of P and V being assumed to be constant for the short period of time here under consideration), the torque due to the drag force F increases progressively and the slippage g of the wheel also increases until, reaching the value corresponding to the maximum value k_1 of the coefficient of friction k. After reaching this value, further increases in the slippage (the rate of rotation n of the wheel decreases) are accompanied by decreases in the drag force F.

If no exterior influence intervenes, this process will continue until the wheel becomes locked (n=o).

Although the vertical load P on the wheel in question might vary from instant to instant, it is obvious that the drag force F will always be at its maximum possible value if the coefficient of friction k between the wheel and the ground is at its k_1 value. Therefore, it may be considered that F follows the same curve with respect to g as does k, for any given value of P.

Considering then that the ordinates of Fig. 2 are proportional to the values of the drag force F, it will be seen that when the slippage is between O and g, (Fig. 2) any change in slippage will be accompanied by a change of F in the same sense; i.e. the time derivative of g will have the same sign as that of F. This region of the curve corresponds to conditions under which it is desired to operate. Conversely, when the system is operating under conditions such that, in Fig. 2 g is between g_1 and 100%, corresponding to the case where C is too great, any increase in the slippage g will be accompanied by a decrease in the drag force F, and vice versa. Therefore the sign of the time derivative of g will, in this case, be opposed to that of the time derivative of F. It may thus be said that when $\frac{dg}{dt}$ has the same sign as $\frac{dF}{dt}$, C must be increased, whereas when these derivatives have opposed signs, C must be decreased.

It will be appreciated that, under these conditions, a correct braking control requires a knowledge, at each instant, of the true ground speed V of the aircraft, of the speed of revolution n of the wheel being braked, and of the braking torque C applied to said wheel, the specific use made of these quantities being described in detail below.

Returning now to Fig. 1, the hydraulic braking servo-control 4 is arranged in such a manner as to be able to cause the application of a regulatable braking torque C to at least one wheel of the landing gear and this servo-control 4 is controlled by an electronic system 5 into which are introduced signals representing, among other quantities, the discussed above parameters. The electronic system, as shown in greater detail in Fig. 4, contains means which are intended to cause the slippage g of wheel 3 to tend toward an optimal value such that k will be near its maximum value. This system 5 comprises, essentially, an analog aircraft landing computer 6 and a regulator 7.

Referring first to computer 6, it is designed and programmed so that, when supplied with input signals containing information indicating the true ground speed V of the aircraft, the braking torque C and the speed of revolution n of the wheel 3 at each instant, it can continuously and regardless of the condition of the landing strip:

(1) First on the basis of the values of C and n, calculate the drag force F exerted on wheel 3;

(2) Then on the basis of the values of V and n, calculate the value of the slippage g of wheel 3;

(3) Then, using the values obtained above, determine the respective signs of $\frac{dg}{dt}$ and $\frac{dF}{dt}$;

(4) Then compare the signs of these two derivatives and generate a binary signal characteristic of this comparison, the duration of this signal being dependent on the persistance of the variations in the data originally introduced into the computer; and

(5) Finally, on the basis of the nature and duration of said binary signal, develop, in a continuously variable manner, a signal representing the assigned slippage g_o, which quantity represents a slippage value which is best adapted to the conditions existing at the moment under consideration, this assigned slippage g_o corresponding to an assigned angular wheel velocity n_o.

Referring now to regulator 7, it may first be noted that it is connected to receive at least two input signals one of which represents the assigned wheel speed n_o and the other of which represents the instantaneous wheel speed n. The regulator is arranged so as to control braking servo-control 4 in such a way as to cause the instantaneous value of n for wheel 3 to be maintained as close as possible to the value of n_o developed by computer 6.

To these ends, and as shown in the embodiment of the electronic system shown in Fig. 4, the computer 6 is fed with three electrical signals the respective values of which represent V, C and n.

The signal relating to the true ground speed V could be obtained either from a speed indicating instrument 8 mounted in the aircraft (as indicated in Figs. 1 and 4) or from an apparatus on the ground (e.g. ground control radar) which transmits a signal indicative of the instantaneous value of the speed V of the aircraft.

With regard to braking torque C exerted on wheel 3, this quantity could advantageously be measured by incorporating brake 3*a* into a dynamometer arrangements carried by landing gear 2. Such an arrangement may, as shown in Fig. 4, be provided by harnessing brake 3*a* to gear 2 through a retaining bar 9. The strains experienced by said bar will then be a function of the braking torque C and they can be measured by a strain gauge 10 which would thus directly furnish an electrical signal indicative of the value of torque C.

According to a non-illustrated modification of the above-described torque measuring means, bar 9 could be replaced by a hydraulic jack equipped with a suitably calibrated manometric measuring instrument capable of responding to changes in the pressure of the fluid contained in said jack, these changes being proportional to the braking torque.

However, in certain cases the presence of a bar 9 or of a hydraulic jack would create problems. In such cases there could advantageously be provided a torque measuring unit comprising a manometric unit mounted in the hydraulic circuit controlling brakes 3*a*. As a matter of fact, supposing the braking effectiveness to remain constant, the variations in the hydraulic braking pressure can be considered as being substantially proportional to the variations in the braking torque C.

Turning now to the determination of the angular wheel velocity *n*, it can easily be measured, as is shown in Fig. 4, by means of an axially mounted tachometer 11 driven by wheel 3, or by means of a counting system utilizing magnetic contacts or photoelectric cells.

DETAILED OPERATION OF COMPUTER 6

The computer shown in Fig. 4 represents one form which this unit may take, and comprises:

An adding unit 12 receiving signal C and a signal $\frac{dn}{dt}$ representing the instantaneous time derivative of wheel velocity n, this derivative having been produced by a differentiating unit 13 receiving, at its input, the signal representing *n*, said adding unit 12 being arranged so as to produce, at its output a signal characteristic of the drag force F applied to wheel 3 and which is equal to

$$F=\frac{I}{R}(C-I\frac{dn}{dt})$$

wherein I represents the moment of inertia of wheel 3 about its axis, both I and R being constant and depending on the nature of wheel 3;

a differentiating unit 14 receiving signal F and producing a signal proportional to $\frac{dF}{dt}$;

an adding unit 15 receiving the signals V and *n* and developing a signal proportional to the slippage *g* according to the formula:

$$g=\frac{V-nR}{V};$$

a differentiating unit 16 receiving signal *g* and delivering a signal $\frac{dg}{dt}$;

a divider circuit 17 into which signals $\frac{dF}{dt}$ and $\frac{dg}{dt}$ are introduced and which produces an output signal proportional to $\frac{dF}{dg}$;

a sign detecting unit 18 receiving the signal representing $\frac{dF}{dg}$, detecting its sign, and producing, at its output, a binary signal equal either to $+U$ or $-U$, depending on the sign of $\frac{dF}{dg}$;

an integrating unit 19 receiving the binary signal produced by unit 18 and delivering a binary signal of variable duration $\pm Ut$;

an adding unit 20 receiving the output from unit 19 and also possibly receiving a constant signal proportional to an initial assigned slippage g_{c1}, said unit 20 producing an output signal proportional to the assigned slippage g_c; and

a final control unit 21 receiving the signals representing g_c and V and delivering at its output a signal representing the optimum, or "assigned" angular wheel velocity n_c.

Referring now to regulator 7, one form of which is shown in Fig. 4, this system comprises:

a comparator unit 22 which receives, on the one hand, the signal n_c developed in computer 6 and, on the other hand, the signal *n* produced by tachometer 11 and produces an error signal $e=n-n_c$ representing the difference between the two input signals;

an amplifier 23 connected to comparator 22 to amplify signal *e* into a signal E;

an adding unit 24 into which are introduced the amplified signal E and a signal proportional to $\frac{dn}{dt}$ (which is equal to $\frac{d(e+n_c)}{dt}$ and therefore to $\frac{de}{dt}+\frac{dn_o}{dt}$ produced by a differentiating unit 13*a* (unit 13*a* could exist as a separate unit in regulator 7 or its function could be fulfilled by the unit 13 of computer 6), which signal $\frac{dn}{dt}$ is due to the fact that $\frac{dn_c}{dt}$ is very small with respect to $\frac{dn}{dt}$, equivalent to $\frac{de}{dt}$, so that adding unit 24 may be considered as receiving input signals representing E and $\frac{de}{dt}$ and delivering at its output, a signal corresponding to $E+\frac{de}{dt}$, and

an amplifier unit 25 which is connected to amplify the $E+\frac{de}{dt}$ signal and which has its output connected to the braking servo-control 4 controlling the operation of brakes 3*a* in such a way as to cause the angular rate of rotation *n* of wheel 3 to approach the assigned value n_o.

The regulator 7 operates in such a way as to cause the circuits 22-25 to make the speed of rotation *n* dependent on the assigned rotating speed n_c given by computer 6. The circuit made up of units 13*a*—24—25 functions to increase the speed of response of the first mentioned circuit by adding to the amplified error signal *e*, its time derivative $\frac{de}{dt}$, so that one obtains a balanced average output which takes into account variations in the error signal *e*.

It should be noted that the various portions of the electrical system 5 can be arranged in ways different from that shown in Fig. 4 and may, in particular, be arranged in the modified ways shown in Figs. 5 and 6, in which figures the same reference numbers represent the same units as those of Fig. 4.

According to the modification shown in Fig. 5, there is provided, at the output of the differentiating unit 14 providing an output proportional to $\frac{dF}{dt}$, a first sign detector 26 and, at the output of the differentiating unit 16 providing an output proportional to $\frac{dg}{dt}$, a second sign detector 27, said sign detectors 26 and 27 each delivering a voltage of amplitude $\pm U_0$ the sign of which depends on the sign respectively, of $\frac{dF}{dt}$ and $\frac{dg}{dt}$.

These voltages $\pm U_0$ are then applied, through diodes 28 to two AND gates 29 and 30, the arrangement of said diodes 28 being such that, if $\frac{dF}{dt}$ and $\frac{dg}{dt}$ are both of the same sign, one of the circuits 29 and 30 will be rendered conductive and will supply a certain current while, if $\frac{dF}{dt}$ and $\frac{dg}{dt}$ are of opposed signs, neither of the AND gates 29 and 30 is fed with current.

The outputs of AND gates 29 and 30 are both delivered to an electronic relay 31 which in turn delivers a binary signal of amplitude U and the sign of which depends on whether or not one of the AND gates is fed with (and delivering) current; i.e. according to the respective signs of $\frac{dF}{dt}$ and $\frac{dg}{dt}$, and thus of the sign of $\frac{dF}{dg}$.

The binary signal is then integrated with respect to time in an integrating unit 19 which delivers a binary signal $\pm Ut$ having a variable duration. This signal is added in adding unit 20, to a constant signal representing an initial assigned slippage g_{ca} to produce a resultant signal representing the instantaneous assigned slippage g_c. This signal is employed by the final control unit 21 to produce a signal proportional to the assigned angular wheel speed n_c.

The modified regulator 7 of Fig. 5, into which is introduced the above mentioned n_c signal, as well as the signal *n* representing the instantaneous angular wheel velocity, is identical with the regulator of Fig. 4, with the exception that, in Fig. 5, a different type of output signal is delivered. For this purpose the linear output amplifier 25 of Fig. 4 is replaced by a sign detector 32 which will deliver a voltage $+U_s$ if error *e* is positive and a voltage $-U_s$ if error *e* is negative.

It may thus be noted that when *g* tends to increase, the servo-control 4 exerts a weaker braking force on brakes 3*a* while if *g* drops below g_c the servo-control receives a signal which causes it to increase the brak-

ing force on brakes 3*a*.

The second modification of the electronic assembly 5 represents a considerable simplification of the preceding one. As a matter of fact, in most situations, and above all if one considers sufficiently short time intervals, when regulator 7 delivers a voltage $+U_s$ (representing an increase in the braking) the instantaneous slippage g tends to increase and $\frac{dg}{dt}$ is positive, whereas when regulator 7 delivers a voltage $-U_s$ (decrease in the braking force) the instantaneous slippage g tends to decrease and $\frac{dg}{dt}$ is negative. Thus, it is possible to dispense with a direct determination of the sign of $\frac{dg}{dt}$ and the knowledge of the sign of this quantity can be determined from the nature of the output of regulator 7. It is therefore possible, as shown in Fig. 6, to eliminate units 15, 16 and 27 (of Fig. 5) and to apply the output from regulator 7, through diodes 28 (suitably arranged), to one input of each of the AND gates 29 and 30.

With this arrangement it may happen that the initial hypothesis is not complied with during a very short portion of one of the braking phases, but, taking into account the speed of response of assembly 5, the harmful effect of such an occurrence will be negligible. This is due to the fact that the deviation is immediately detected by computer 6 then cancelled the next instant by regulator 7.

Returning now to the means 8 (Figs. 1 and 4) for measuring the aircraft true ground speed V, it may be noted that this function may be performed by any number of well-known means, such as a Doppler radar or a tachometer attached to a non-braked wheel. However, it seems preferable to employ an arrangement which represents a complementary feature of this invention, and which can be utilized independently of the principal structure of this invention. This measuring means may be used in any device requiring a signal proportional to the velocity V.

The above described means, as shown in the block 8 of Fig. 4, comprises:

an accelerometer 33, advantageously of the inertia type, mounted in aircraft 1 and arranged to measure the longitudinal accelerations $\frac{dV}{dt}$; and

an intergrating unit 34 receiving the output of unit 33 and a reference signal n_o characteristic of the velocity V_o of the aircraft prior to the application of any braking force, this signal n_o being advantageously delivered from the tachometer 11 which was described above.

The instantaneous velocity V of the aircraft can be represented by the expression:

$$V = V_o - \int_o^t \frac{dV}{dt}\, dt, \text{ or}$$

$$V = n_o R - \int_o^t \frac{dV}{dt}\, dt$$

Turning now to Fig. 7 there is shown, in a detailed manner, one possible form of the hydraulic system constituting the servo-control 4 permitting the actuation of the brake 3*a* through the intermediary of a servo-valve 35 controlled by regulator 7.

According to the arrangement shown, the manual braking control operative by the pilot, for example a pedal 36, is operatively connected with an electrical transmitter 37 delivering to regulator 7 a signal of an intensity variable with the magnitude of travel of pedal 36. Due to this arrangement, the intensity of the signal sent by regulator 7 to the driving motor 38 of servo-valve 35, and accordingly the maximum pressure level which said servo-valve 35 can deliver, and in a general manner the braking action, can be controlled by the pilot by a mere depression, applying more or less effort of said pedal 36.

Servo-valve 35 may advantageously be fed by a pump 39 through the intermediary of a one-way valve 40 and a pressure accumulator 41, the return of fluid being provided for by a tank 42.

In the case where the present invention is mounted in a piloted aircraft there is placed at the disposition of the pilot a switch 36*a* mounted in the power circuit of electrical assembly 5. This switch permits the operation of assembly 5 to be turned on or off, thus rendering the automatic braking either operative or non-operative, while the pedal 36 gives the pilot the possibility of limiting the level of the automatic braking.

Thus, the braking may be performed, at the will of the pilot, in one of the three following ways:

When switch 36*a* is closed (automatic braking) and pedal 36 is depressed to the maximum (no limitation of the level of automatic braking), an optimum braking is provided, which assures the stopping of the aircraft in a minimum distance;

When the switch 36*a* is closed (automatic braking) and pedal 36 is only partially depressed (limitation of the automatic braking level), an optimum braking is provided be-

low the braking level fixed by the pilot, the aircraft stopping distance being obviously greater than in the preceding case, such an arrangement enabling the pilot to stop at any desired point on the landing strip; or

When switch 36*a* is open (automatic braking inoperative), the braking level is only dependent on the position of pedal 36 (ordinary manually controlled braking).

Moreover, the pilot generally also has at his disposal an emergency brake system which could use certain elements of the above-described device.

The present invention may also be used in a pilotless aircraft, in which case the closing of switch 36*a*, and if desired the operation of pedal 36, would be effected by remote control.

Another embodiment of the invention relating to a particularly simple construction of computer 6 will now be described.

In this embodiment, the drag force F exerted on wheel 3 (and calculated from the braking torque C exerted on the wheel and from the angularly velocity *n* of said wheel) is sent to a circuit operating as a detector of maximums.

For this purpose, and as shown by Fig. 8, computer 6 comprises, as in the above embodiment, adding unit 12 which receives signal C and signal $\frac{dn}{dt}$ (produced from the signal *n* in differentiating unit 13).

The characteristic signal of drag force F is then sent:

on the one hand to a detector circuit 43 comprising a diode 44, a capacitor 45 and a relay 46 capable of discharging, when it is energized, capacitor 45;

and on the other hand to a differential amplifier 47 which also receives the discharge current of the capacitor 45 of detector circuit 43.

The output of differential amplifier 47 is then connected:

on the one hand to relay 46;

and on the other hand to a chain comprising in series a Schmitt trigger circuit 48, a binary circuit 49 and an adding unit 50 delivering a binary signal $\pm U$.

This binary signal $\pm U$ is integrated in an integrating unit 51 which therefore delivers the binary signal $\pm Ut$ of variable duration.

Signal $\pm Ut$ is transformed in a control unit 52 which also receives the signal V characteristic of the velocity of the aircraft, said control unit then delivering signal Vg_r defined by the following relation

$$Vg_r = V - Rn_r$$

R being the radius of wheel 3.

Finally, an adding unit 53, receiving signals Vg_r and V, delivers signal n_r.

The capacitor (45) is charged by a strong impedance-diode (44)—; this capacitor (45) cannot therefore be discharged in a very short time. It is necessary, in order to discharge this capacitor (45), that the relay (46) be excited.

If F varies from F_a to F_b when g varies from g_a to g_b, the theoretical function $F_{(g)}$ passes through the maximum F_M corresponding to $g = g_M$.

When F increases from F_a to F_M, the voltage at the terminals of the capacitor (45) increases from U_{ca} to U_{cM} and it remains equal to U_{cM} when F diminishes from F_M to F_b, since the capacitor (45) cannot discharge during this very short time.

Therefore, when g increases from g_a to g_b the voltage at the terminals of the capacitor (45), voltage U_c which constitute the signal representing F, increases from U_{ca} to U_{cM}. The derivative of this voltage with respect to the slippage $\frac{dU_c}{dg}$ is positive or zero in the interval (g_a, g_b), which leads to considering that $\frac{dF}{d_g}$ is not negative, therefore for that $\frac{dF}{d_g}$ greater than or equal to O. The cain (47), (48), (49), (50) then delivers a signal $+U$, integrated to give the signal $+Ut$ so far as it can be considered that $\frac{dF}{d_g}$ greater than or equal to O.

Inversely, if F varies from F_b to F_a when g varies from G_b to g_a, the theoretical function $F_{(g)}$ passes through the maximum F_M corresponding to $g = g_M$.

When F increases from F_b to F_M the voltage at the terminals of the capacitor (45) increases from U_{cb} to U_{cM}. The derivative of this voltage with respect to the slippage $\frac{dU_c}{dg}$ is negative or zero in the interval (g_b, g_a), which leads to considering that $\frac{dF}{d_g}$ is not positive, therefore that $\frac{dF}{d_g}$ less than or equal to O.

The chain (47), (48), (49), (50) then delivers a signal $-U$, integrated to give the signal $-Ut$ so far as it can be considered that $\frac{dF}{d_g}$ less than or equal to O.

When the differential amplifier (47) detects a difference between U_{cM} and F greater than a detection threshold D, the relay (46) is excited and discharges the capacitor (45), which permits a new determination of the maximum value of F.

The output signal n_o of computer 6 made according to the last described embodiment is then fed to regulator 7, which is for instance identical to those above described.

Finally Fig. 10 shows a braking system particularly interesting when the hydraulic braking circuit servo-control 4 includes a pressure operated servo-valve. In this case it may be considered that the transfer function of said servo-valve is constant within a very short time interval. It is then possible to dispense with the measurement of the torque C exerted on wheel 3 since this torque C is proportional to the signal $\pm U_s$ delivered by regulator 7.

Computer 6 then receives, as shown by Figure 10, in addition to the signals representative of the instantaneous angular speed *n* of the wheel and of the velocity V of the aircraft, the signal $\pm U_s$ delivered by regulator 7.

WHAT WE CLAIM IS:—

1. A braking sytem for vehicles adapted to run on the ground, comprising at least one servo-control arranged so as to be capable of producing on at least one wheel of radius R and of inertia moment I belonging to the vehicle to be braked an adjustable braking torque, the said servo-control being subjected to an electronic system into which is introduced information relating to the movements of the said vehicle, more particularly information relating to the speed V of the vehicle itself, the braking torque C exerted on the braked wheel and the instantaneous angular speed n of the said wheel, characterised in that the electronic system comprises, (A) a computer capable, at each instant and whatever the state of the ground, (a) of producing a binary signal $\pm$ Ut of variable duration, the sign of this binary signal $\pm$ Ut being the sign of the derivative of the drag force $F = \frac{1}{R}(C - I\frac{dn}{dt})$ relatively to the slippage $g = 1 - \frac{nR}{V}$, whereas the duration of this binary signal $\pm$ Ut is equal to the time during which the said derivative $\frac{dF}{dg}$ retains the same sign, the sign of this derivative $\frac{dF}{dg}$ being determined directly or indirectly, and (b) of using the sign and the duration of this binary signal $\pm$ Ut to produce another signal g_o known as the "assigned slippage" signal representing a slippage better adapted to the conditions existing at the instant in question, this assigned slippage g_c corresponding to an angular speed n_c of the braked wheel, known as the "assigned angular speed", and (B) a regulator receiving, amongst other information, an information relating to the said desired angular speed n_c and an information relating to the instantaneous angular speed n of the braked wheel, the said regulator acting on the said servo-control in such a manner that the value of the instantaneous angular speed n is maintained at the value of the desired angular speed n_o calculated by the computer.

2. A braking system according to Claim 1, characterised in that the speed of the vehicle V itself relatively to the ground is determined by (a) an accelerometer advantageously of an inertia type which is situated on board the vehicle and is arranged so as to be capable of measuring the longitudinal accelerations thereof, and (b) an intergrating unit receiving the signal emitted by the said accelerometer and a reference signal characteristic of the initial conditions, *i.e.* before braking, as regards the said vehicle speed V.

3. A braking system according to Claim 1, characterised in that the signal g_c characteristic of the assigned slippage is produced in an adding unit receiving the binary signal $\pm$ Ut of variable duration and possibly a signal representing an assigned slippage set once and for all at the input of the said adding unit.

4. A braking system according to Claim 1, characterised in that the signal n_c characteristic of the assigned angular speed, corresponding to the assigned slippage g_c, is produced in a control unit receiving the signal g_c representing the assigned slippage and a signal representing the speed V of the vehicle itself.

5. A braking system according to Claim 1, characterised in that the regulator comprises a comparator unit receiving the signals representing the assigned angular speed n_c and the instantaneous angular speed n, and emitting an error signal e equal to the difference between the two said signals.

6. A braking system according to Claim 5, characterised in that the error signal e is amplified to a signal E to which there is added, in an adding unit, its derivative relatively to time, the signal $E + \frac{de}{dt}$ thus developed then acting on the servo-control.

7. A braking system according to Claim 1, characterised in that the regulator is arranged so as to emit an output voltage $\pm U_s$, the sign of this output voltage corresponding to the sign of the difference between the two signals representing respectively the assigned angular speed n_c and the instantaneous angular speed n.

8. A braking system according to Claim 1 wherein the computer comprises means for calculating separately the derivatives relatively to time of the drag force F and the slippage g, characterised in that the signs of the said two derivatives are compared in a divider circuit followed by a sign detecting unit which emits at its output a voltage $\pm$ U the sign of which is that of the derivative of the drag force F relatively to the slippage g, the said voltage $\pm$ U being then integrated in an integrating unit which produces the variable-duration binary signal $\pm$ Ut.

9. A braking system according to Claim 1 wherein the computer comprises means for separately calculating the derivatives relatively to time of the drag force F and the slippage g, characterised in that the respective signs of the two said derivatives are detected separately in a first sign detector and in a second sign detector, each emitting a voltage $\pm U_o$ the sign of which is that of the corresponding derivative $\frac{dF}{dt}$ or $\frac{dq}{dt}$, the said voltage $\pm U_o$ being applied by means of four diodes to two circuits of the AND type co-operating with a relay, the said assembly, composed of diodes, AND circuits, and a relay, being arranged in such a manner that the said relay delivers a voltage $\pm$ U the sign of which is that of the derivative of the drag force F relatively to the slippage g, the said voltage $\pm$ U being then integrated in an integrating unit which produces the variable-duration binary signal $\pm$ Ut.

10. A braking system according to Claim 7 wherein the computer comprises means for calculating the derivative relatively to time of the drag force F, characterised in that the sign of the said derivative is detected in a sign detector producing a voltage $\pm U_o$ the sign of which is that of the derivative $\frac{dF}{dt}$, this voltage $\pm U_o$ being, with the output voltage $\pm U_s$ delivered by the regulator, applied by means of four diodes to two AND circuits co-operating with a relay, this assembly consisting of diodes, AND circuits and a relay being arranged in such a manner that the said relay delivers a voltage $\pm$ U the sign of which is that of the derivative of the drag force F relatively to the slippage g, the said voltage $\pm$ U being then integrated in an integrating unit which produces the variable-duration binary signal $\pm$ Ut.

11. A braking system according to Claim 1, characterised in that the drag force F is introduced into a maximum detector circuit which co-operates with a chain comprising a circuit of the "Schmitt trigger" type, a binary circuit and an adding unit, the said chain delivering a voltage $\pm$ U the sign of which is that of the derivative of the drag force F relatively to the slippage g, the said voltage $\pm$ U being then integrated in an integrating unit which produces the variable-duration binary signal $\pm$ Ut.

12. A braking system according to Claim 11, characterised in that the maximum detector circuit comprises a diode, a capacitor and a relay capable of discharging the capacitor when it is energised.

13. A braking system according to Claim 12, characterised in that the signal characteristic of the drag force F is transmitted (a) to the maximum detector circuit and (b) to a differential amplifier which also receives the discharge current of the capacitor of the maximum detector circuit, the output of this differential amplifier being connected to the relay of the said maximum detector circuit and to the chain comprising the "Schmitt trigger", binary circuit and adding unit.

14. A braking system according to Claim 7 wherein the servo-control comprises a pressure-dependent servo-valve, characterised in that the information relating to the braking torque C is constituted by the output voltage $\pm U_s$ produced by the regulator.

15. A computer controlled wheel braking system constructed and arranged substantially as described herein with reference to Figures 1 to 4, 7, 8 and 9 of the accompanying drawings, or as modified in any one of Figures 5, 6 and 10 thereof.

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SHEET 1

Fig.1.

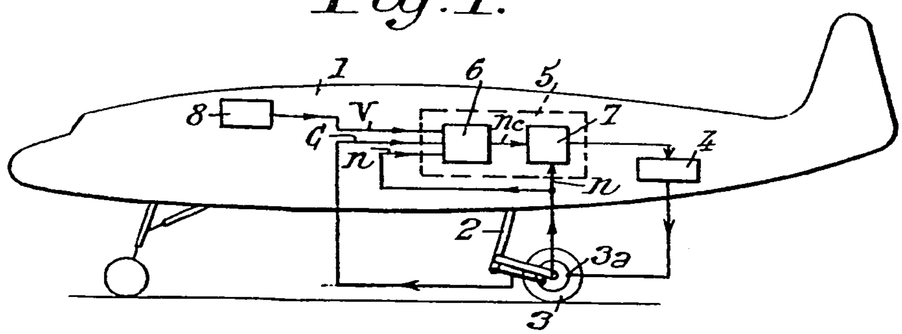


Fig.7

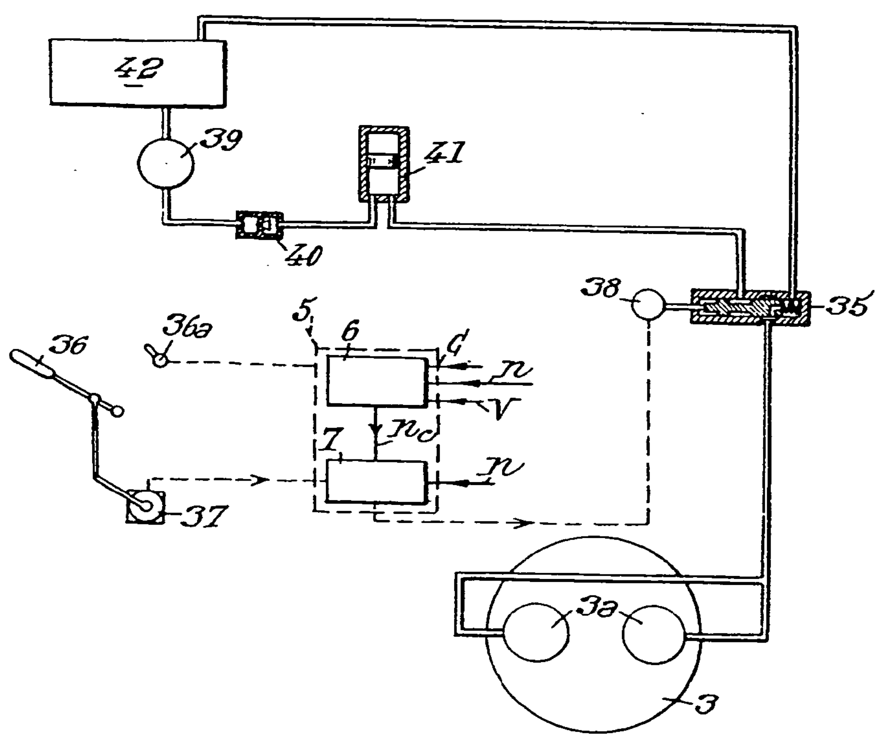


Fig. 2.

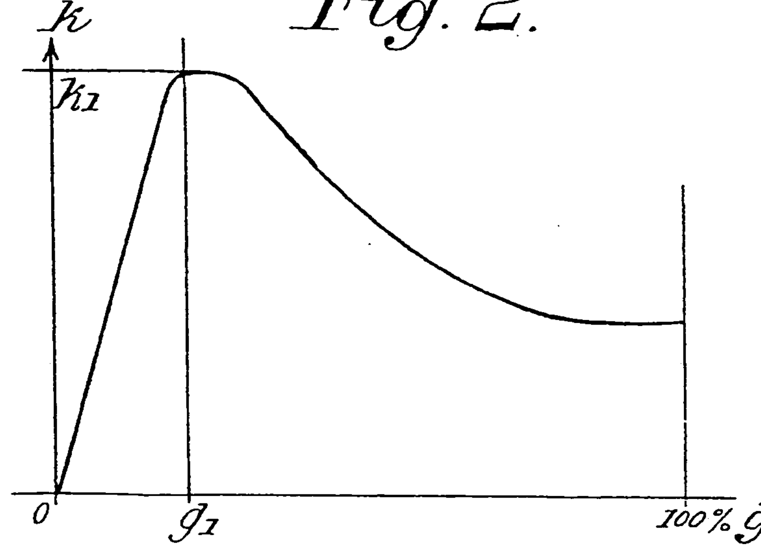
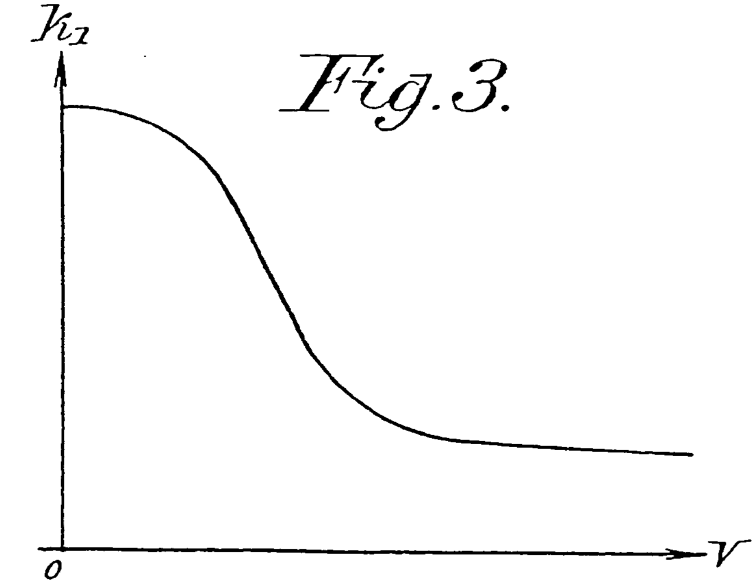


Fig. 3.



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SHEETS 2 & 3

Fig. 4.

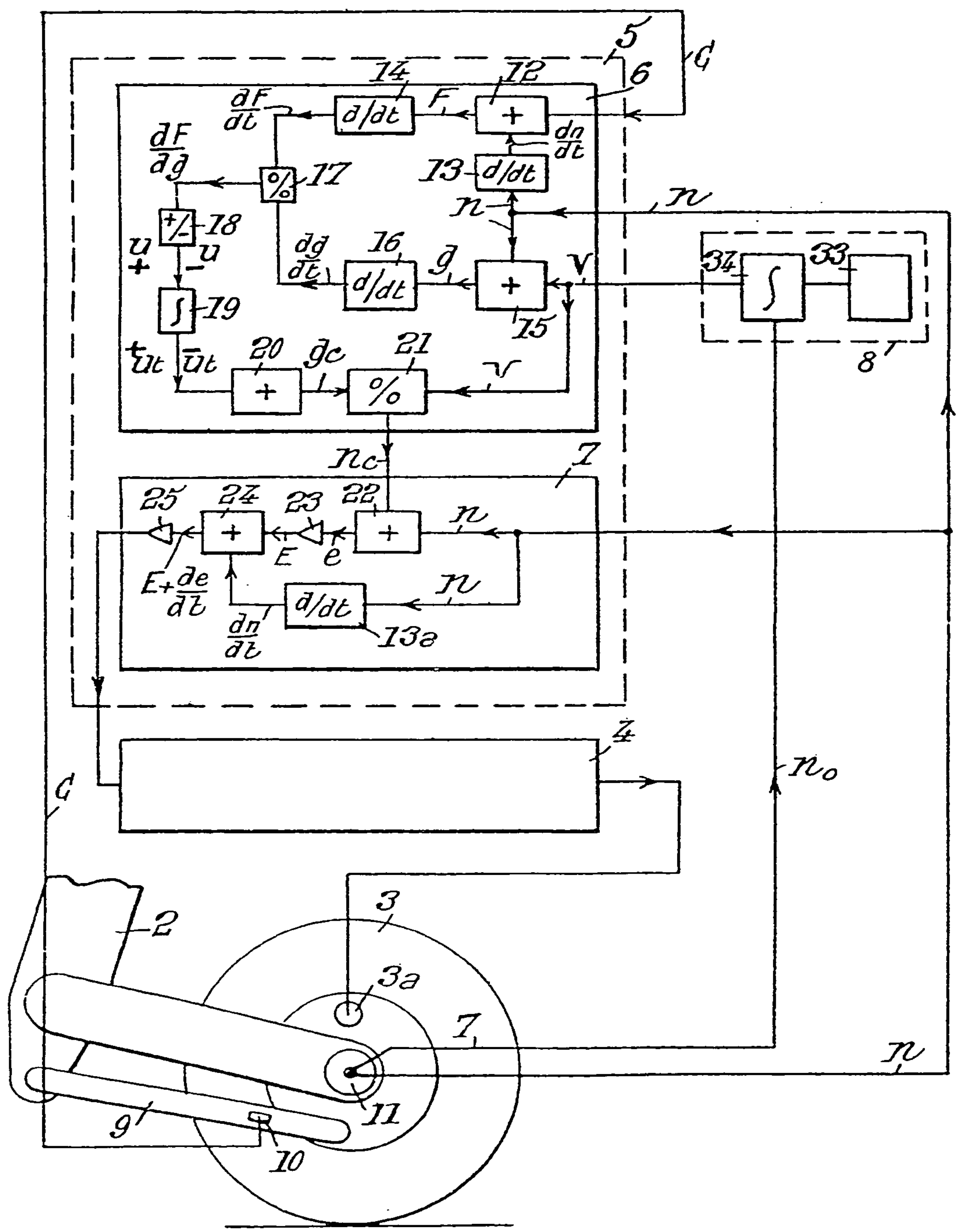


Fig. 2.

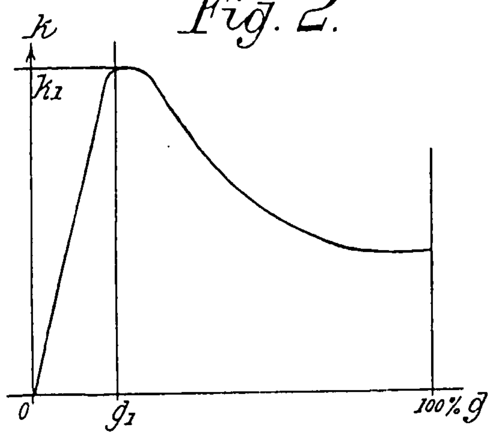


Fig. 3.

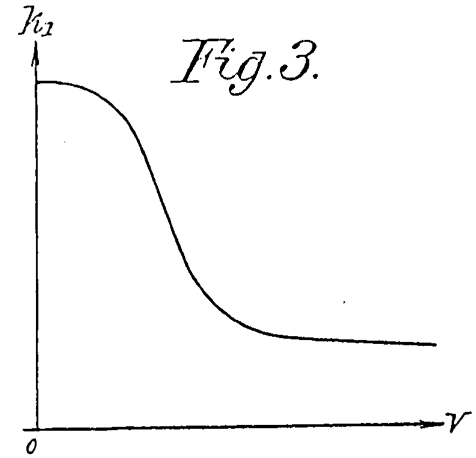


Fig. 4.

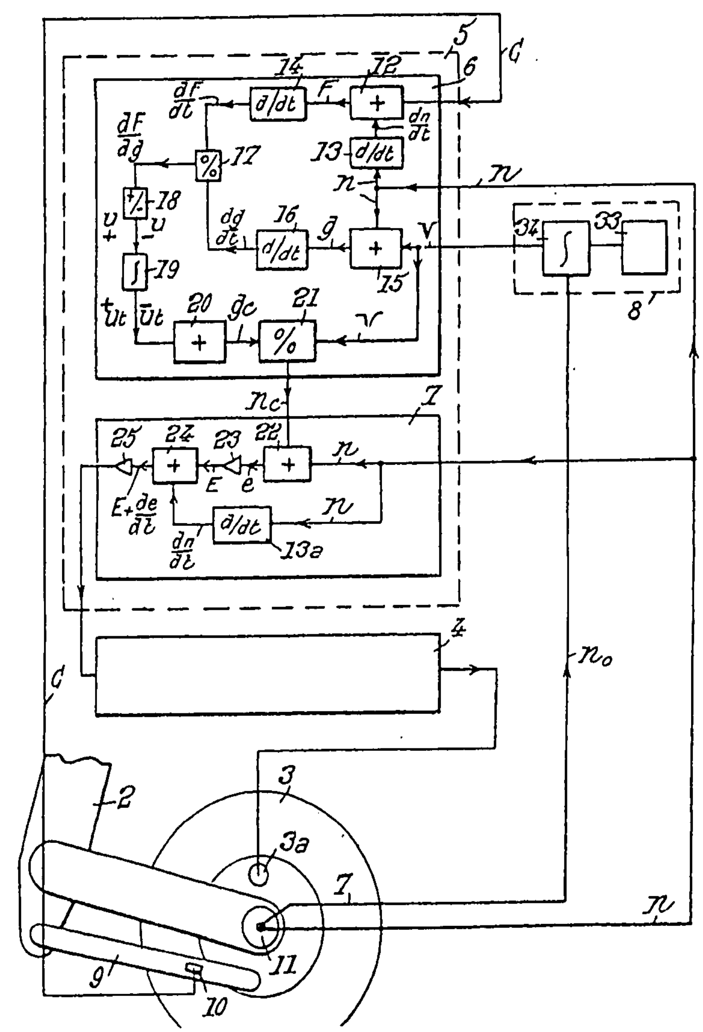
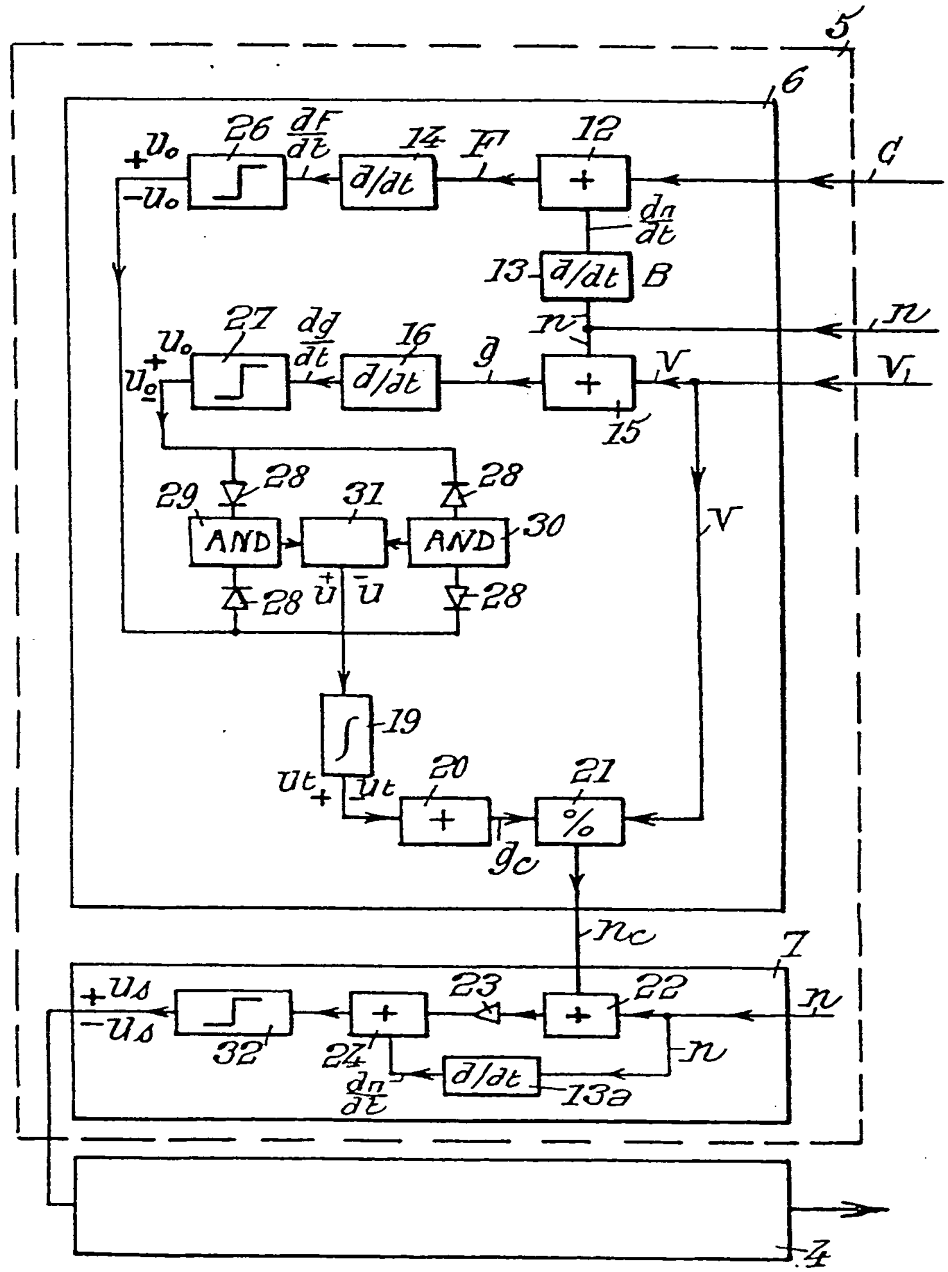


Fig. 5.



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SHEETS 4 & 5

Fig. 6.

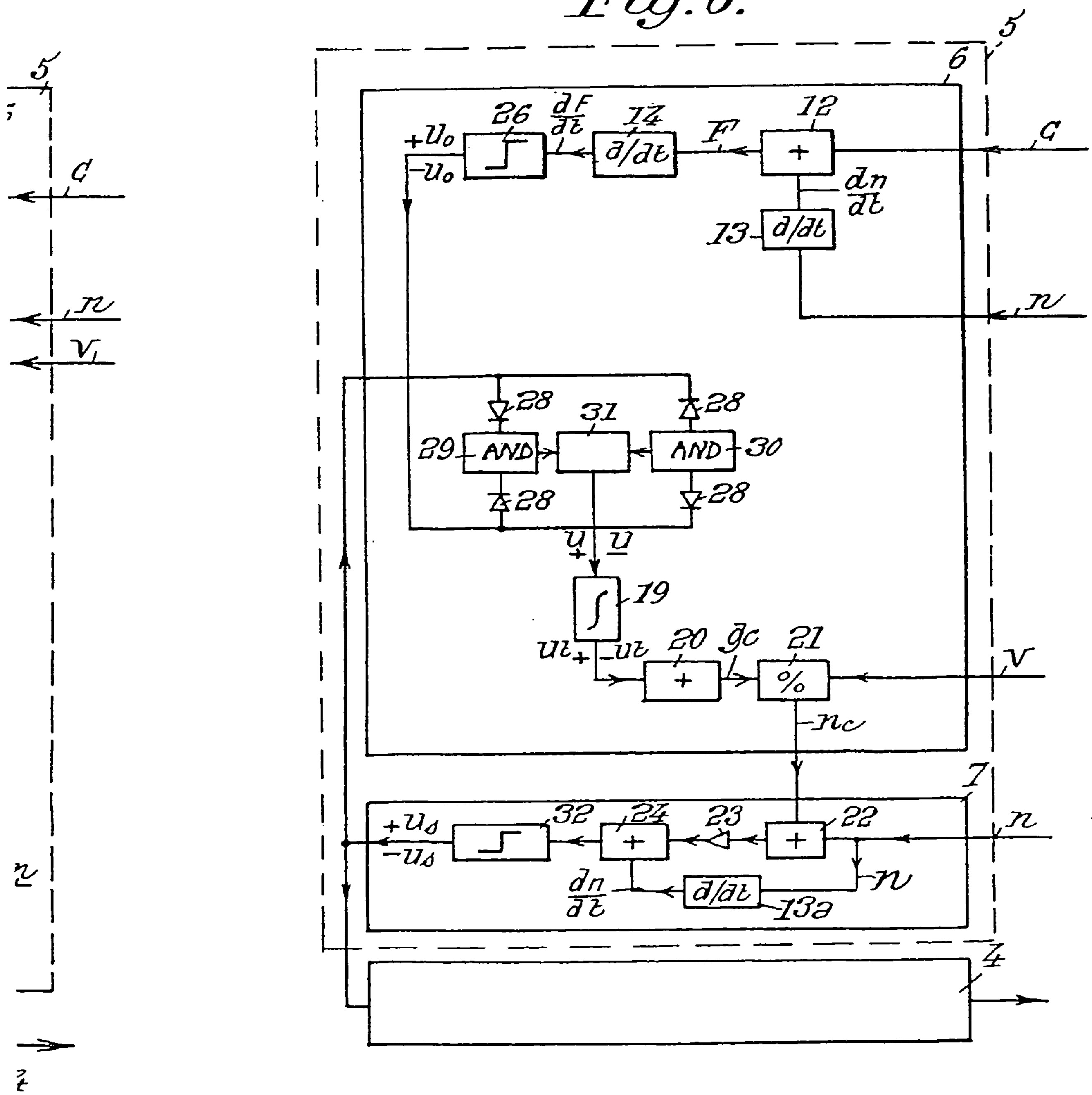
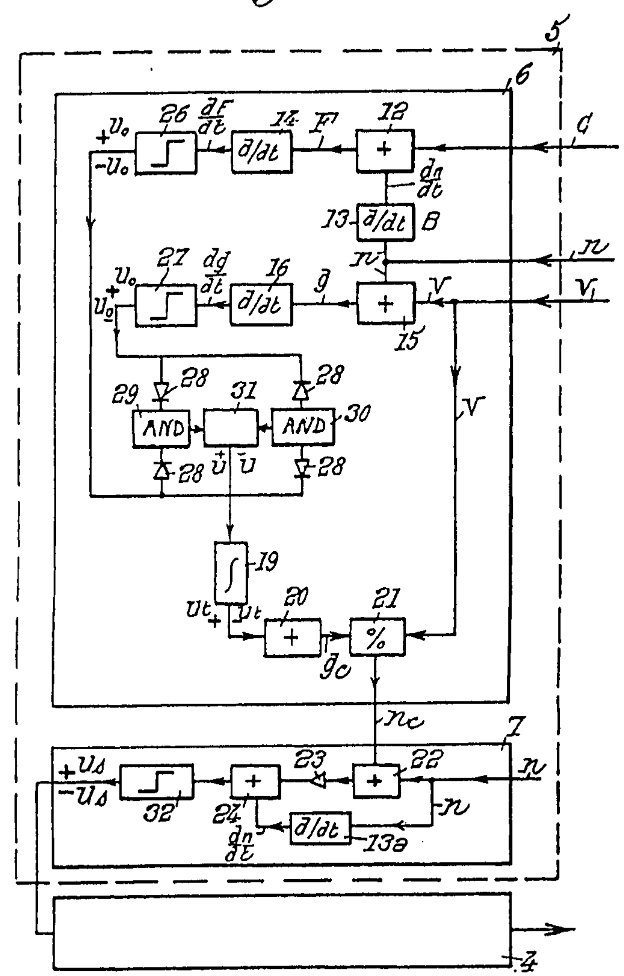


Fig. 5.



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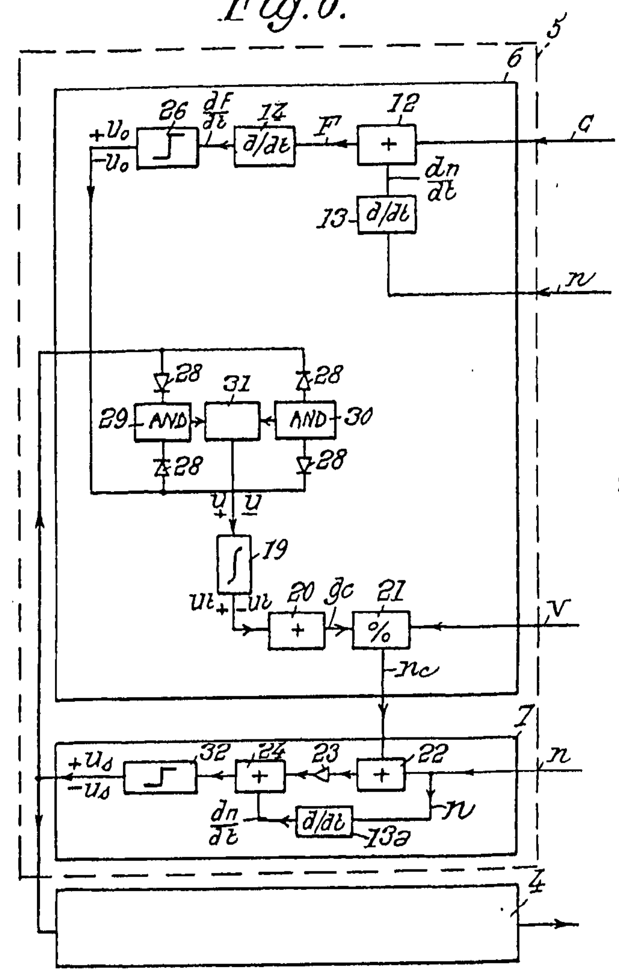
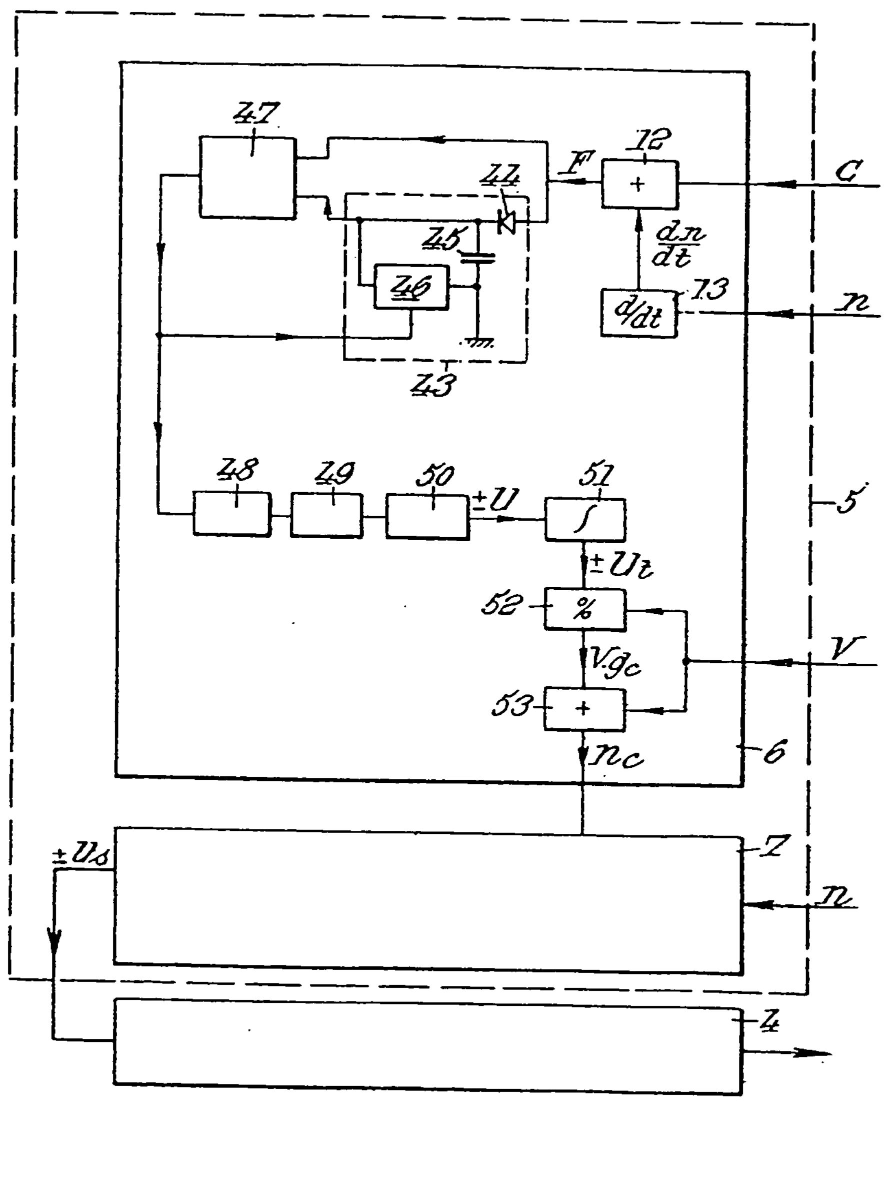


Fig.8.



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SHEETS 6 & 7

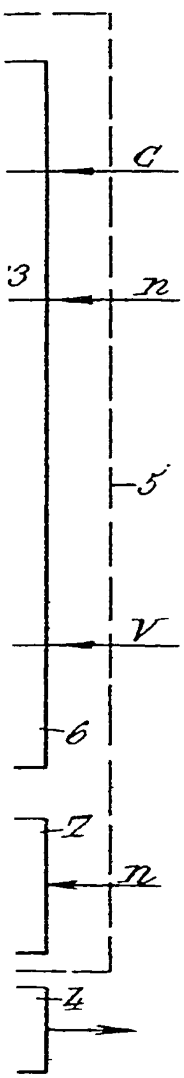


Fig. 10.

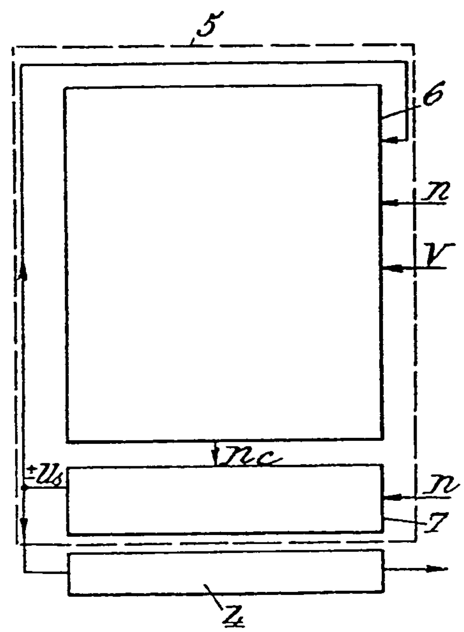
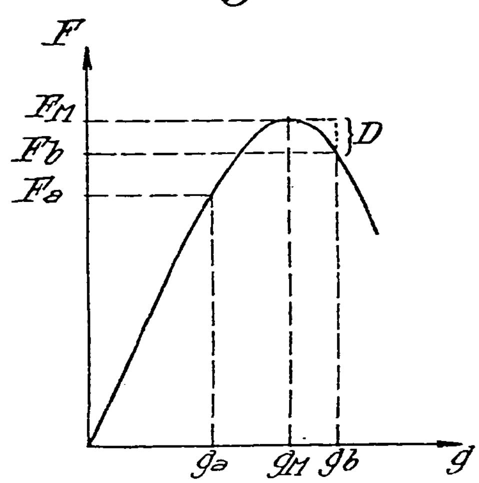


Fig. 9.



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SHEETS 6 & 7

Fig. 8.

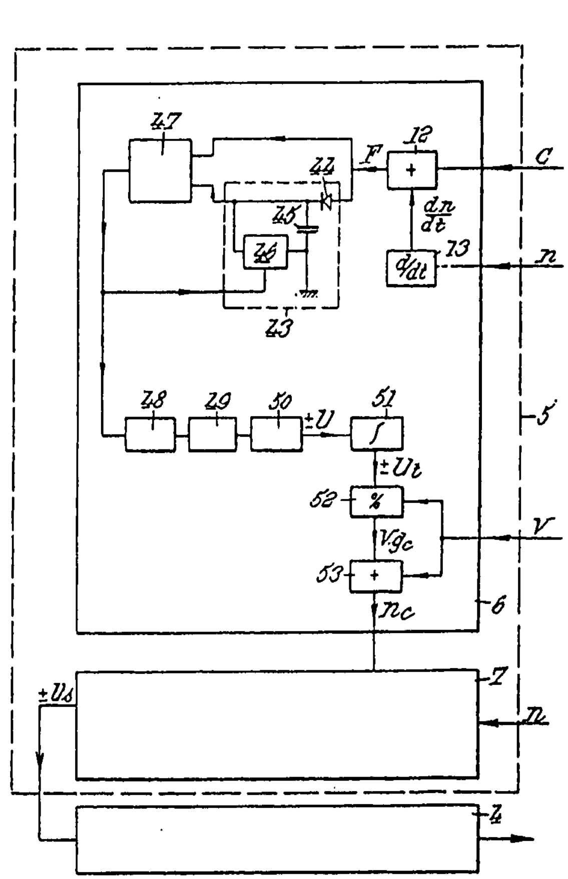

Fig. 10.

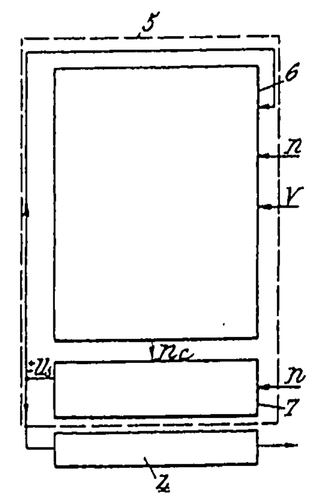

Fig. 9.